U.S. Patent Application No. 10/005,783
Applicant: Lewis et al.
Title: Methods And Systems For Developing
Data Flow Programs
Docket No: 30014200-1005
Sheet 1 of 39 Sheets

FIG. 1

U.S. Patent Application No. 10/005,783
Applicant: Lewis et al.
Title: Methods And Systems For Developing
Data Flow Programs
Docket No: 30014200-1005
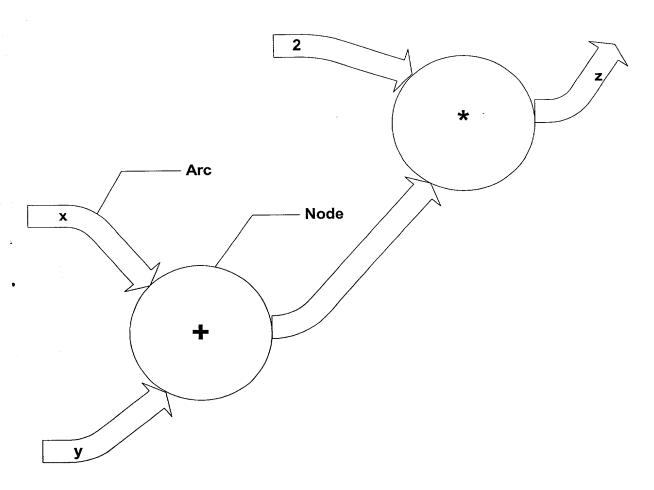Sheet 2 of 39 Sheets

(1,1)	(1,2)	(1,3)	(1,4)
(2,1)	(2,2)	(2,3)	(2,4)
(3,1)	(3,2)	(3,3)	(3,4)
(4,1)	(4,2)	(4,3)	(4,4)

— 200

204

| (1,2) | (1,3) | (1,4) |

(1,1)

(2,1)

— 202

(3,1)

(4,1)

(2,2)	(2,3)	(2,4)
(3,2)	(3,3)	(3,4)
(4,2)	(4,3)	(4,4)

— 206

FIG 2

U.S. Patent Application No. 10/005,783
Applicant: Lewis et al.
Title: Methods And Systems For Developing
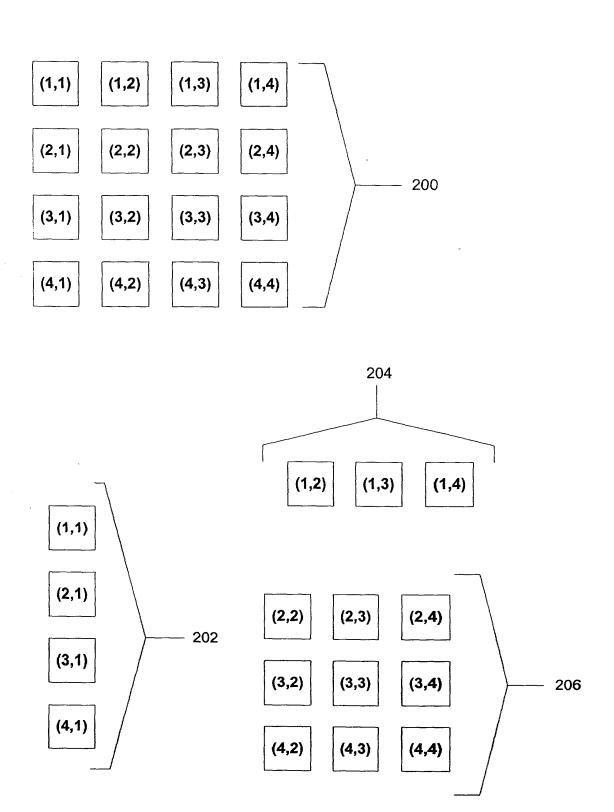Data Flow Programs
Docket No: 30014200-1005
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FIG. 3A

U.S. Patent Application No. 10/005,783
Applicant: Lewis et al.
Title: Methods And Systems For Developing
Data Flow Programs
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(1,1)   (1,2)   (1,3)   (1,4)

(2,1)   (2,2)   (2,3)   (2,4)   200

(3,1)   (3,2)   (3,3)   (3,4)

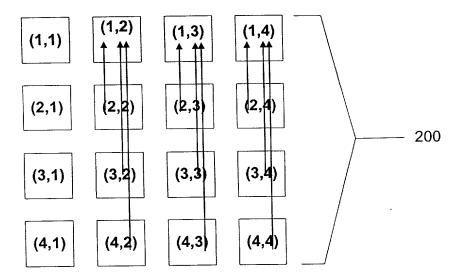(4,1)   (4,2)   (4,3)   (4,4)

FIG. 3B

U.S. Patent Application No. 10/005,783
Applicant: Lewis et al.
Title: Methods And Systems For Developing
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Blocks sharing
same (first) state

Blocks sharing
same (second) state

Blocks sharing
same (third) state

FIG. 4

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Applicant: Lewis et al.
Title: Methods And Systems For Developing
Data Flow Programs
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500

510

Data Flow
Program ——— 524

Development
Tool ——— 522

DAG ——— 526

Step Tree ——— 528

Memory

520

Secondary
Storage Device ——— 530

CPU ——— 540

560 ——— Video Display

Input Device ——— 550
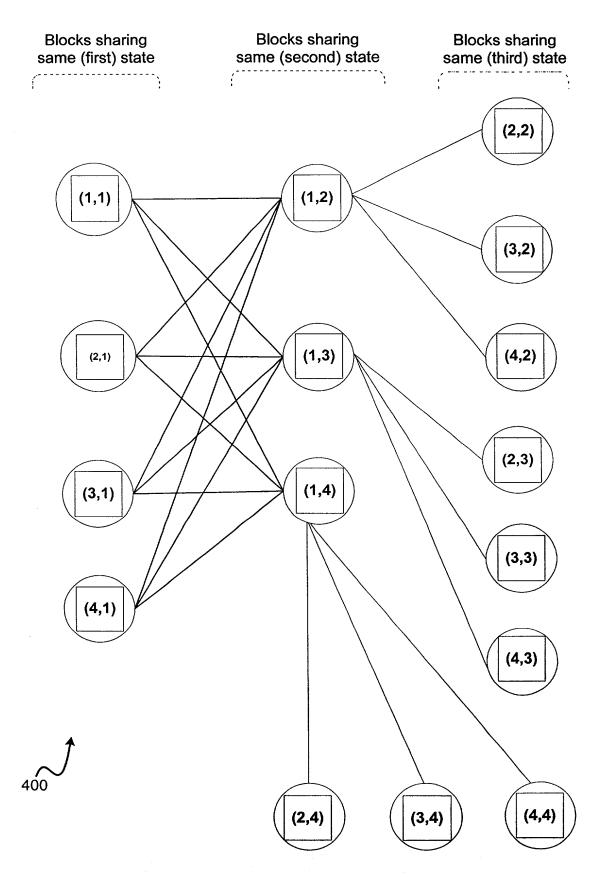
NETWORK ——— 570

FIG. 5

U.S. Patent Application No. 10/005,783
Applicant: Lewis et al.
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Developing Data Flow Programs
Docket No: 30014200-1005
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600

Begin

— 610
Define Memory Region

— 620
Divide Memory Region Into Blocks

— 630
Any More Blocks? N

Y

— 640
Select Block

— 650
Identify Other Block(s) that Influence the Block's Final State

— 660
Identify the Portion of the Control Flow Program Used to Operate on the Block

— 670
Establish Dependency Links Between Blocks

— 675
Produce source code for generating a DAG of nodes and dependencies at run-time.

— 680
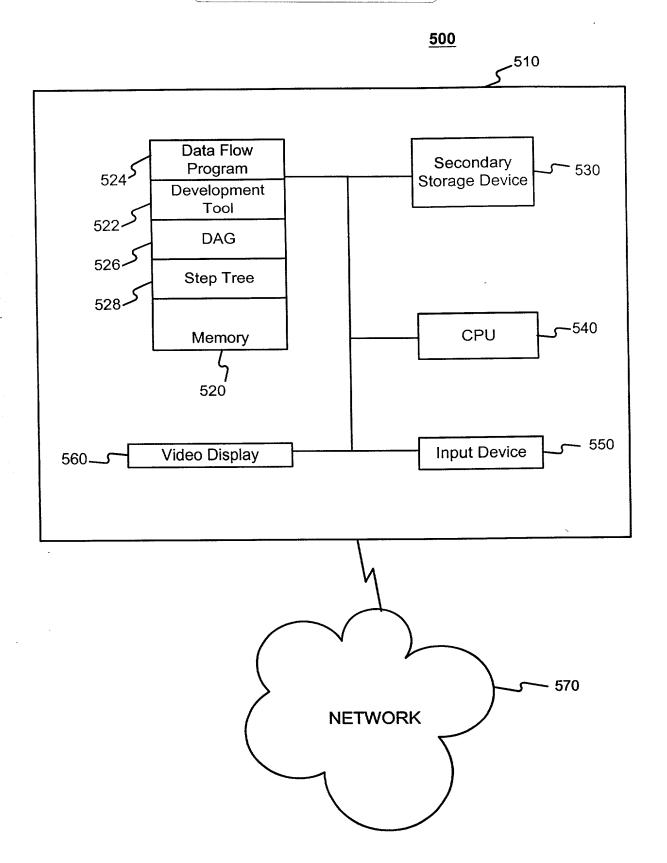During run-time, Put All Nodes in Queue for Execution

End

FIG. 6

U.S. Patent Application No. 10/005,783
Applicant: Lewis et al.
Title: Methods And Systems For Developing
Data Flow Programs
Docket No: 30014200-1005
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700

1	2	3	4	5
(1,1)	(2,1)	(3,1)	(4,1)	(1,2)

6	7	8	9	10
(1,3)	(1,4)	(2,2)	(3,2)	(4,2)

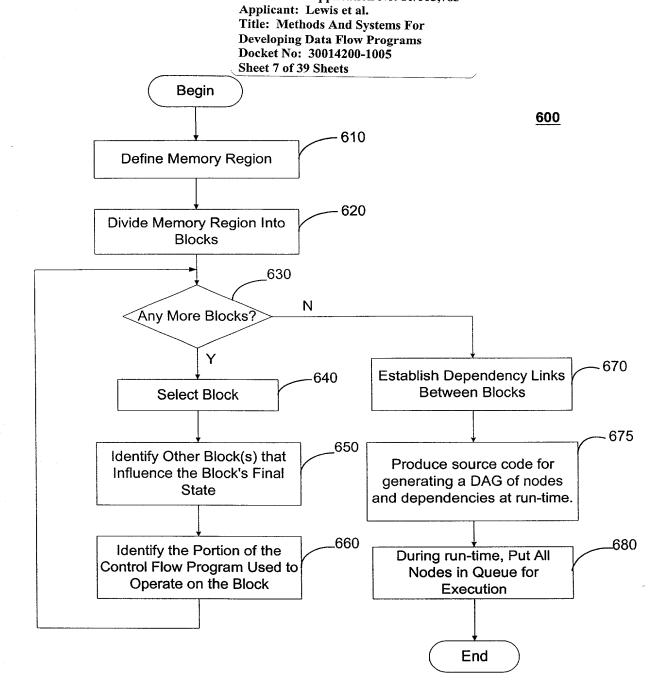| 11	12	13	14	15	16
(2,3)	(3,3)	(4,3)	(2,4)	(3,4)	(4,4)

QUEUE

FIG. 7

U.S. Patent Application No. 10/005,783
Applicant: Lewis et al.
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810   **800**

**Multiprocessor
Computer System**

830

Shared Memory

Processor   Processor   * * *   Processor

840a   840b   840n
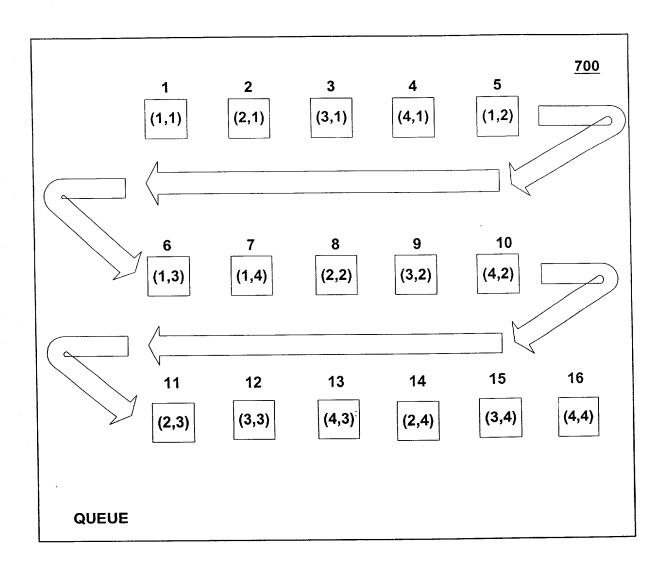
NETWORK INTERFACE   820

FIG. 8

U.S. Patent Application No. 10/005,783
Applicant: Lewis et al.
Title: Methods And Systems For Developing
Data Flow Programs
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900

Begin

910
Any Thread Available?

N

Y

920
Any Blocks in Queue?

N

Y

930
Select Block

950
Skip Block

N

940
All Blocks upon which selected Block depends, if any, completed execution?

Y

960
Execute Control Flow on Block

End

FIG. 9

U.S. Patent Application No. 10/005,783
Applicant: Lewis et al.
Title: Methods And Systems For Developing
Data Flow Programs
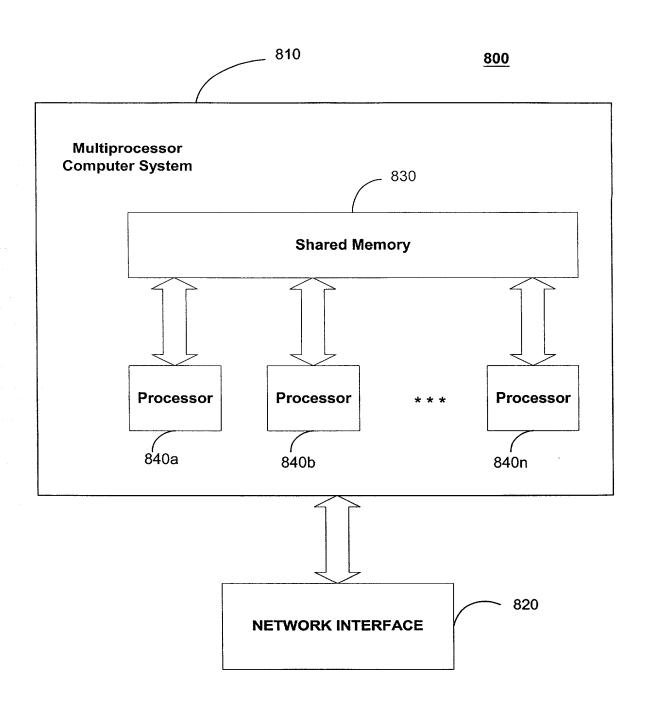Docket No: 30014200-1005
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FIG. 10A

U.S. Patent Application No. 10/005,783
Applicant: Lewis et al.
Title: Methods And Systems For Developing
Data Flow Programs
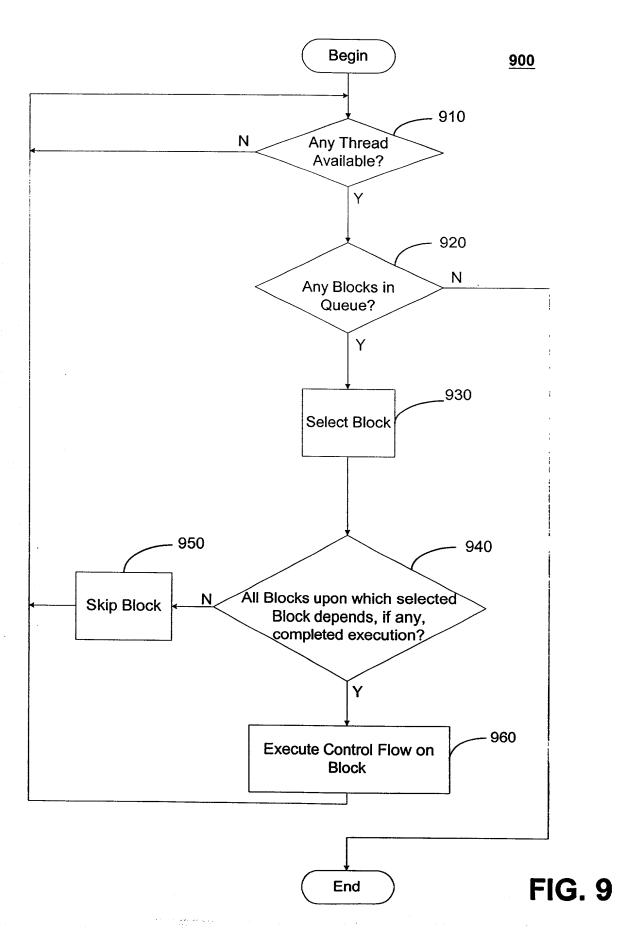Docket No: 30014200-1005
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QUEUE

1	2	3	4	5
(1,1)	(2,1)	(3,1)	(4,1)	(1,2)

*

THREADS

THREAD   THREAD   THREAD   THREAD   * * *

PROCESSORS

PROCESSOR   PROCESSOR   PROCESSOR   PROCESSOR

FIG. 10B

U.S. Patent Application No. 10/005,783
Applicant: Lewis et al.
Title: Methods And Systems For Developing
Data Flow Programs
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QUEUE

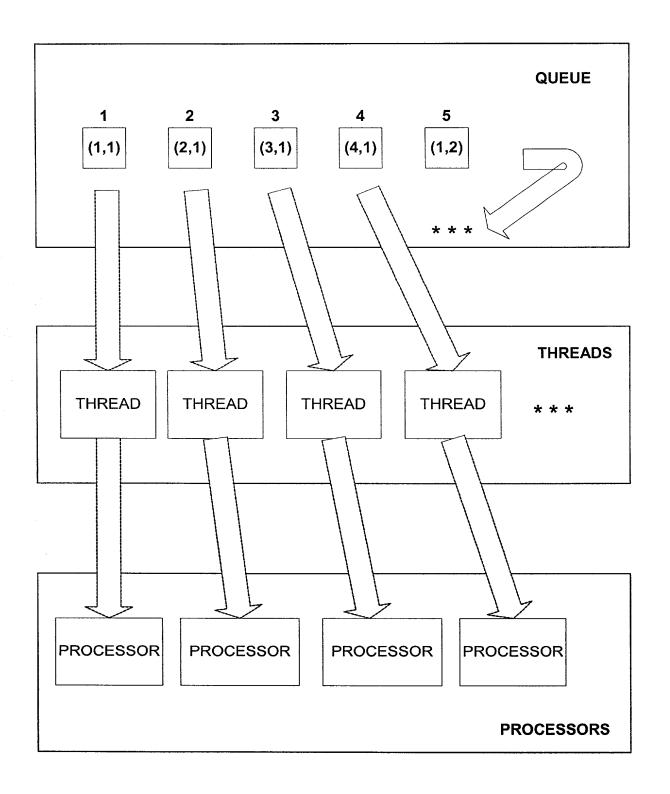| 1	2	3	4	5
(1,1)	(2,1)	(3,1)	(4,1)	(1,2)

* * *

THREADS

THREAD	THREAD	THREAD	THREAD	* * *

PROCESSORS

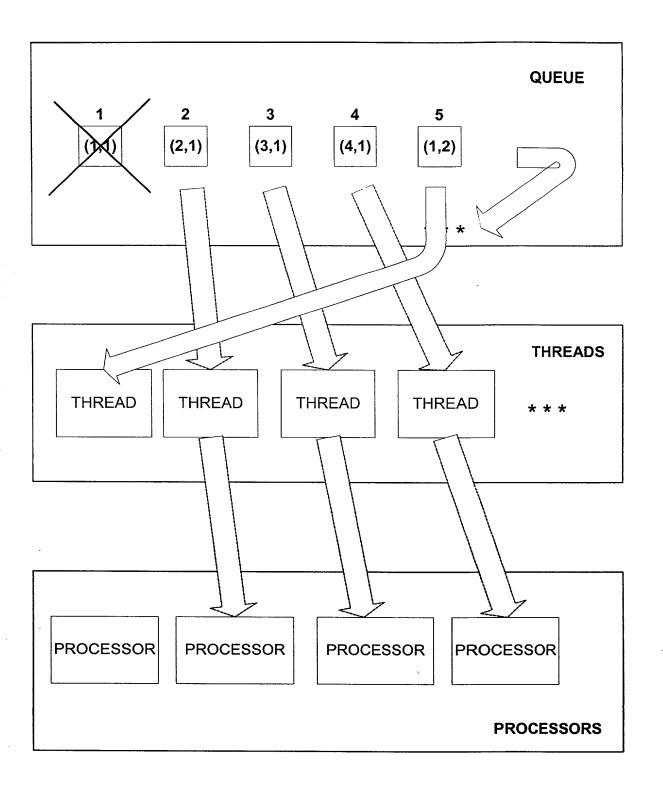| PROCESSOR	PROCESSOR	PROCESSOR	PROCESSOR

FIG 10C

U.S. Patent Application No. 10/005,783
Applicant: Lewis et al.
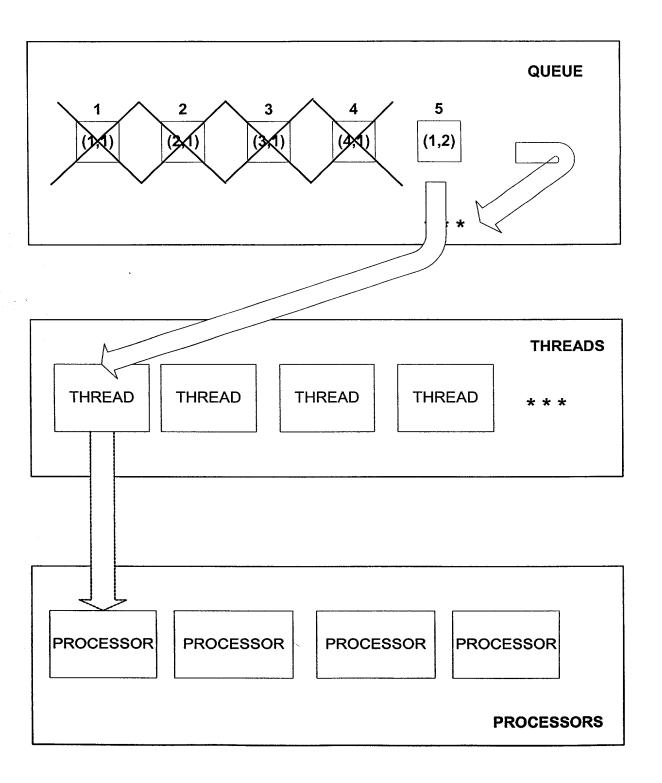Title: Methods And Systems For
Developing Data Flow Programs
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1100

1102

FIG. 11

U.S. Patent Application No. 10/005,783
Applicant: Lewis et al.
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Fixed Row, Fixed Column

1202

P

1204

Fig. 12A

Free Row, Fixed Column

1202

P

1204

Fig. 12B

Fixed Row, Free Column

1202

P

1204

Fig. 12C

Free Row, Free Column

1202

P

1204

Fig. 12D

U.S. Patent Application No. 10/005,783
Applicant: Lewis et al.
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Data Flow Programs
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A

Secondary Multiple
Row

B

Secondary Multiple
Column

C

Primary Single

FIG. 13

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Applicant: Lewis et al.
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Data Flow Programs
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A

Primary Multiple

Secondary
Multiple Row

B

Primary Multiple

Secondary Multiple
Column

C

Primary Single

FIG. 14

U.S. Patent Application No. 10/005,783
Applicant: Lewis et al.
Title: Methods And Systems For
Developing Data Flow Programs
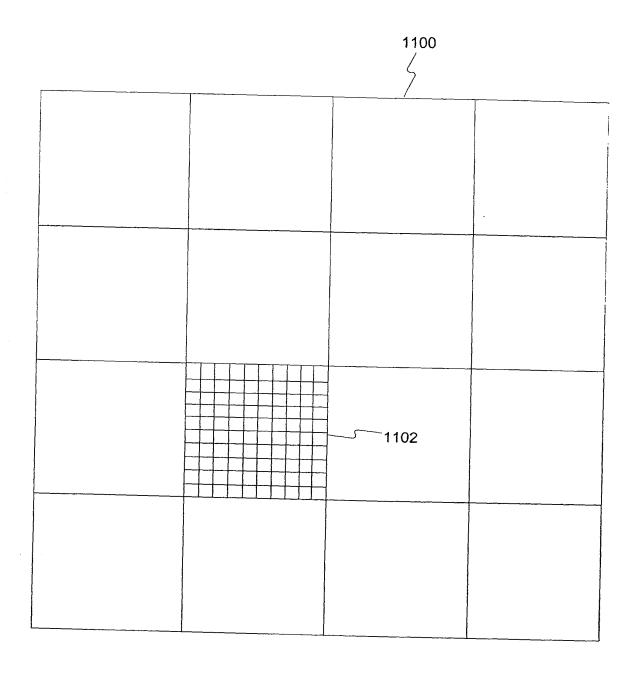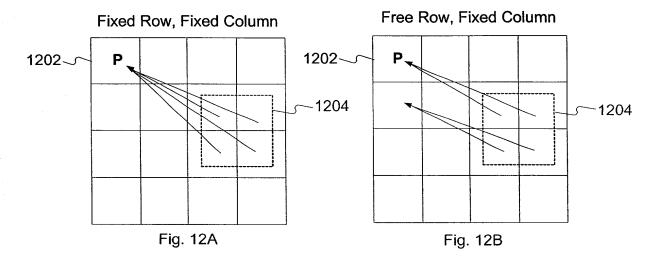Docket No: 30014200-1005
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A

B

C

Secondary All

Primary Single

Secondary Multiple
Column

Primary Single

Secondary Multiple
Column

FIG. 15A

A

B

C

Secondary All

Primary Multiple Transpose

Secondary
Multiple
Column
Transpose

Primary Single

Secondary Multiple
Column

FIG. 15B

U.S. Patent Application No. 10/005,783
Applicant: Lewis et al.
Title: Methods And Systems For Developing
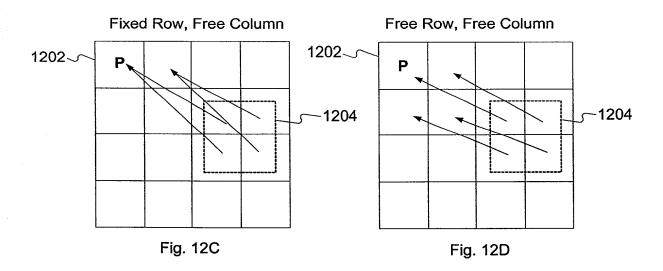Data Flow Programs
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FIG. 16

U.S. Patent Application No. 10/005,783
Applicant: Lewis et al.
Title: Methods And Systems For Developing
Data Flow Programs
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FIG. 17

U.S. Patent Application No. 10/005,783
Applicant: Lewis et al.
Title: Methods And Systems For Developing
Data Flow Programs
Docket No: 30014200-1005
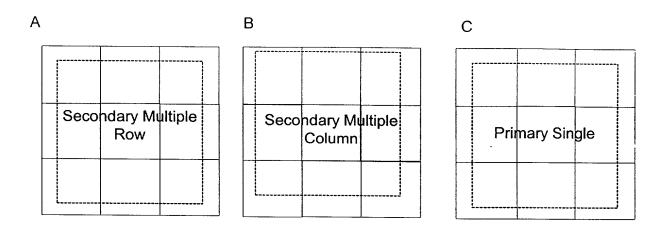Sheet 22 of 39 Sheets

Begin

Receive Indication to Run Program — 1802

Processor Available? — 1804
N

Y

Select Block of Code From Queue — 1806

All Dependencies for Selected Block Met? — 1808
N

Y

Execute Selected Block on Processor — 1810

Modify Node for Selected Block to Indicate Code is Executing — 1812

Execution of Block Complete? — 1814
N

Y

Modify Node for Selected Block to Indicate Code Execution is Complete — 1816

Modify Appearance of Dependency Links out of Selected Block — 1818

Any More Blocks? — 1820
Y   N

End

FIG. 18

U.S. Patent Application No. 10/005,783
Applicant: Lewis et al.
Title: Methods And Systems For Developing
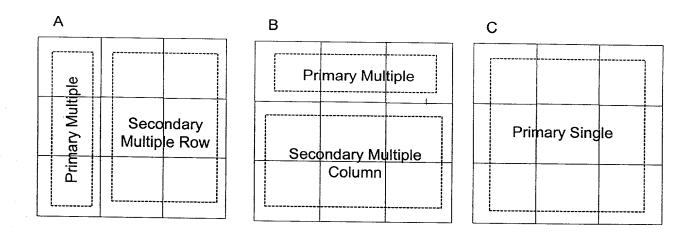Data Flow Programs
Docket No: 30014200-1005
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FIG. 19

U.S. Patent Application No. 10/005,783
Applicant: Lewis et al.
Title: Methods And Systems For Developing
Data Flow Programs
Docket No: 30014200-1005
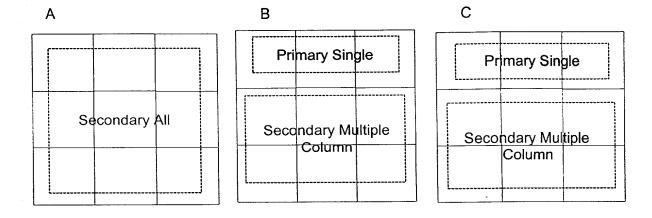Sheet 24 of 39 Sheets

2000

FIG. 20

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Applicant: Lewis et al.
Title: Methods And Systems For Developing
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FIG. 21

U.S. Patent Application No. 10/005,783
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FIG. 22

U.S. Patent Application No. 10/005,783
Applicant: Lewis et al.
Title: Methods And Systems For Developing
Data Flow Programs
Docket No: 30014200-1005
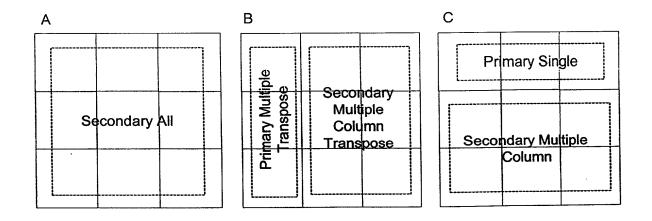Sheet 27 of 39 Sheets

2300

FIG. 23

U.S. Patent Application No. 10/005,783
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2400

2402 — (1, 1)

2404 — (2, 1)

2406 — (3, 1)

2408 — (4, 1)

2410 — (1, 2)

2412 — (1, 3)

2414 — (1, 4)

2, 2 — 2416

3, 2 — 2418

4, 2 — 2420

2, 3

3, 3

4, 3

2, 4

3, 4

4, 4

FIG. 24

U.S. Patent Application No. 10/005,783
Applicant: Lewis et al.
Title: Methods And Systems For Developing
Data Flow Programs
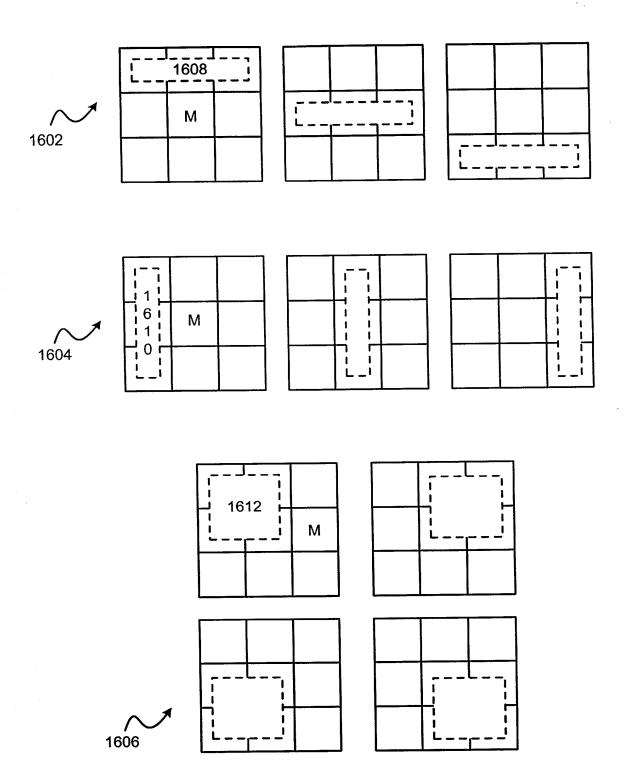Docket No: 30014200-1005
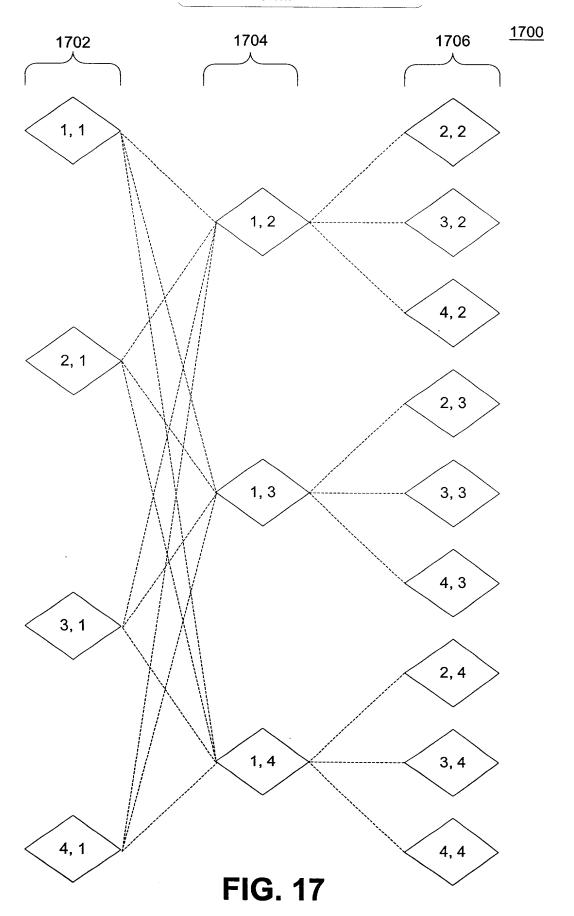Sheet 29 of 39 Sheets

2500

FIG. 25

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Figure 26

U.S. Patent Application No. 10/005,783
Applicant: Lewis et al.
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Data Flow Programs
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```
        ( Begin )
            │
            ▼
┌─────────────────────────────┐
│  Determine selected data for │
│         monitoring           │
│                      2702    │
└─────────────────────────────┘
            │
            ▼
┌─────────────────────────────┐
│ Provide graphical representation of │
│         selected data        │
│                      2704    │
└─────────────────────────────┘
            │
            ▼
┌─────────────────────────────┐
│ Monitor modifications to selected │
│ data as code segments execute │
│                      2706    │
└─────────────────────────────┘
            │
            ▼
┌─────────────────────────────┐
│  Highlight data affected by code │
│          segments            │
│                      2708    │
└─────────────────────────────┘
```

(1,1) □ M   ～ 2703

(1,1) M1 M2
       M3 M4 ～ 2705

(1,1) ▨ □
       □ ▨ ～ 2709

2700

Figure 27

U.S. Patent Application No. 10/005,783
Applicant: Lewis et al.
Title: Methods And Systems For Developing
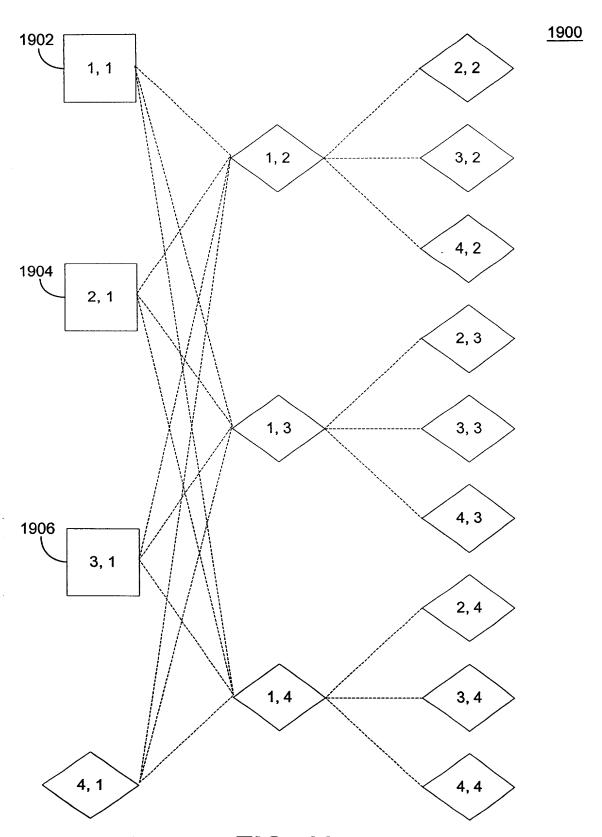Data Flow Programs
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```
          ┌─────────────┐
          │    Begin    │
          └──────┬──────┘
                 │
                 ▼
   ┌──────────────────────────┐
   │ Determine selected threads│
   │                           │
   │                    2802   │
   └──────────────┬───────────┘
                  │
                  ▼
   ┌──────────────────────────┐
   │ Display the nodes executed│
   │  by the selected threads. │
   │                    2804   │
   └──────────────┬───────────┘
                  │
                  ▼
          ┌─────────────┐
          │     End     │
          └─────────────┘
```

○ Thread1
◉ Thread2
◉ Thread3   2803

Thread2   Thread3   2805

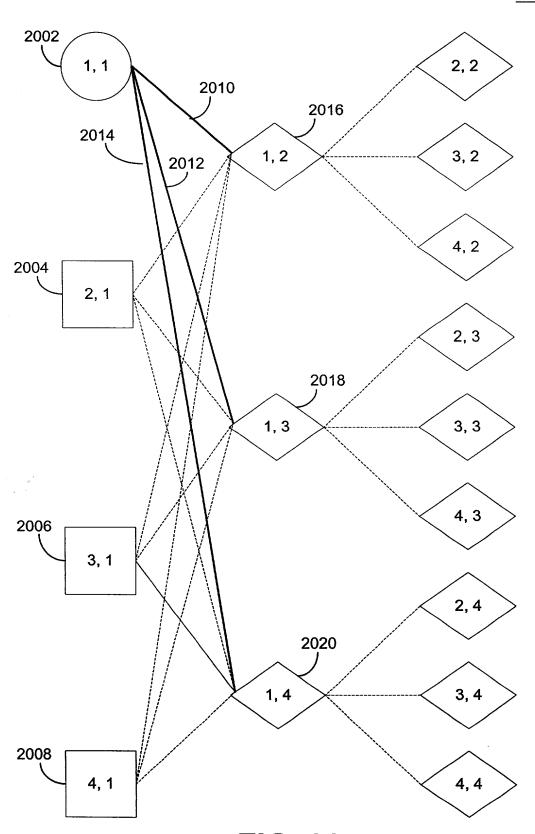| 1,1 | 2,2 | | 3,3 |

| 1,2 | 2,3 | | 3,4 |

2800

Figure 28

U.S. Patent Application No. 10/005,783
Applicant: Lewis et al.
Title: Methods And Systems For Developing
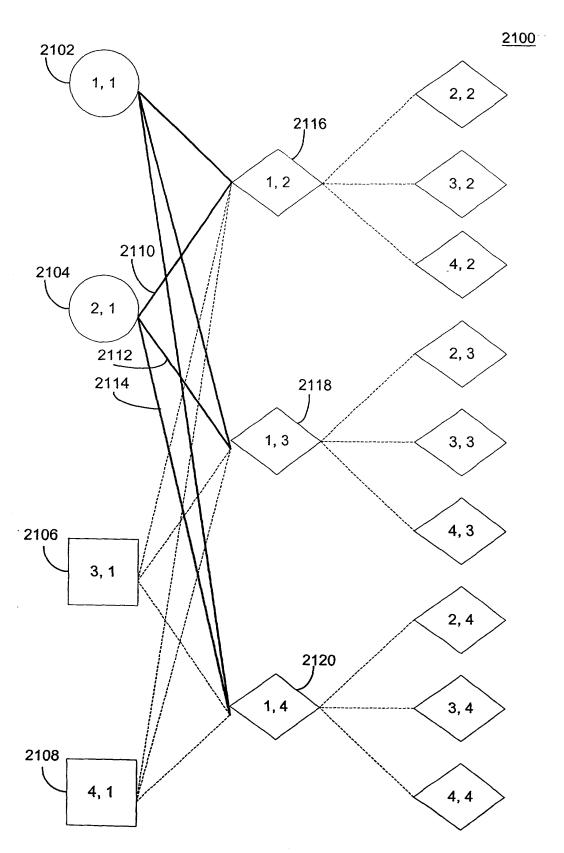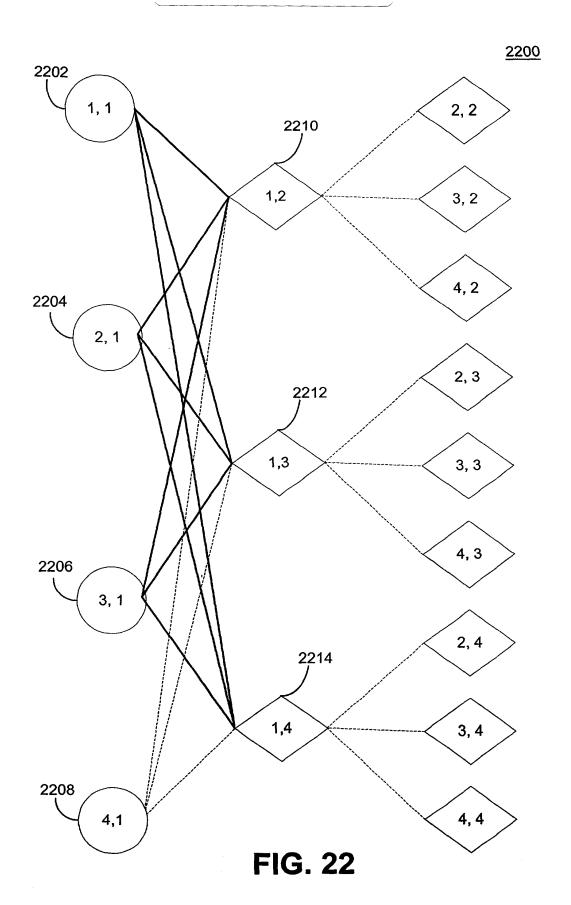Data Flow Programs
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```
                    ┌──────────────┐
                    │    Begin     │
                    └──────────────┘
                           │
                           ▼
              ┌──────────────────────────┐
              │   Obtain indication of   │
              │   next node to process   │
              │          2902            │
              └──────────────────────────┘
                           │
                           ▼
              ┌──────────────────────────┐
              │     Highlight node       │
              │          2904            │
              └──────────────────────────┘
                           │
                           ▼
              ┌──────────────────────────┐
              │       Determine          │
              │     dependencies for     │
              │      selected node       │
              │          2906            │
              └──────────────────────────┘
                           │
                           ▼
              ┌──────────────────────────┐
              │     Execute code to      │
              │   satisfy dependencies   │
              │     for selected node    │
              │          2908            │
              └──────────────────────────┘
                           │
                           ▼
              ┌──────────────────────────┐
              │     Execute code for     │
              │     selected node.       │
              │                          │
              │          2910            │
              └──────────────────────────┘
                           │
                           ▼
                    ┌──────────────┐
                    │     End      │
                    └──────────────┘
```
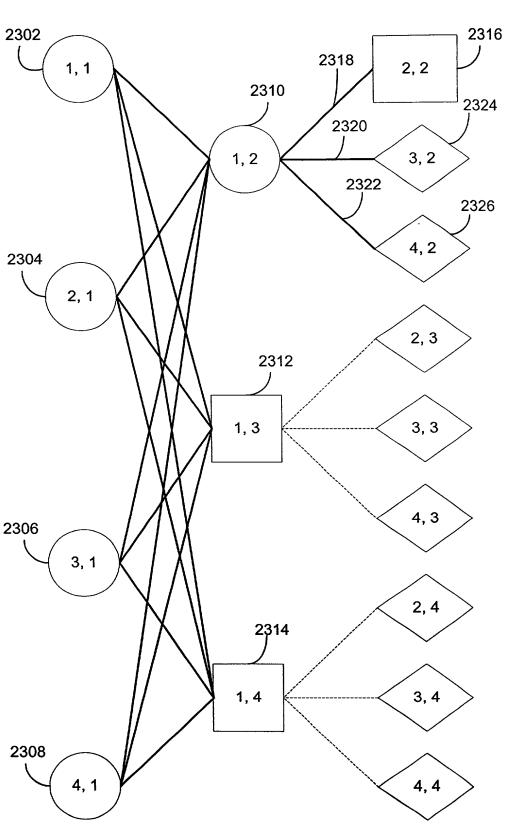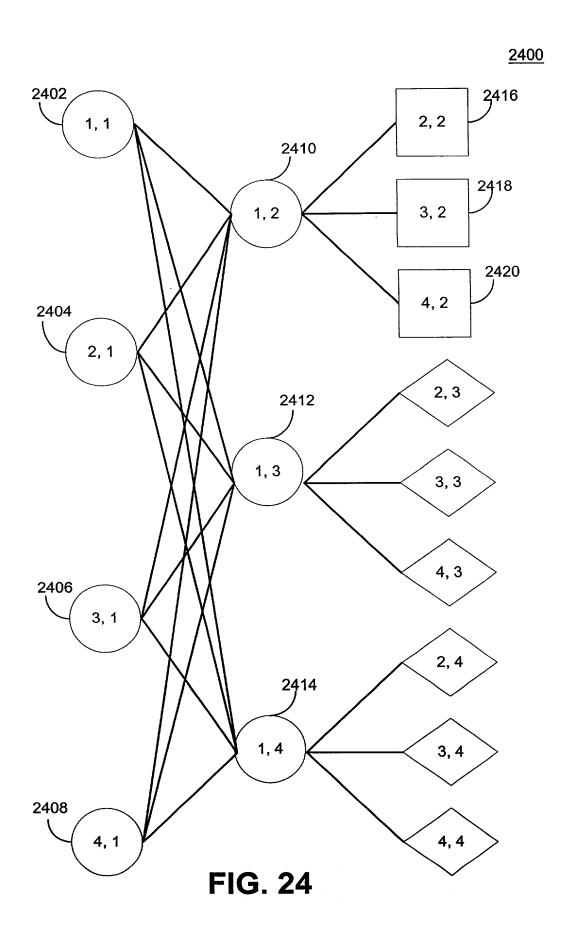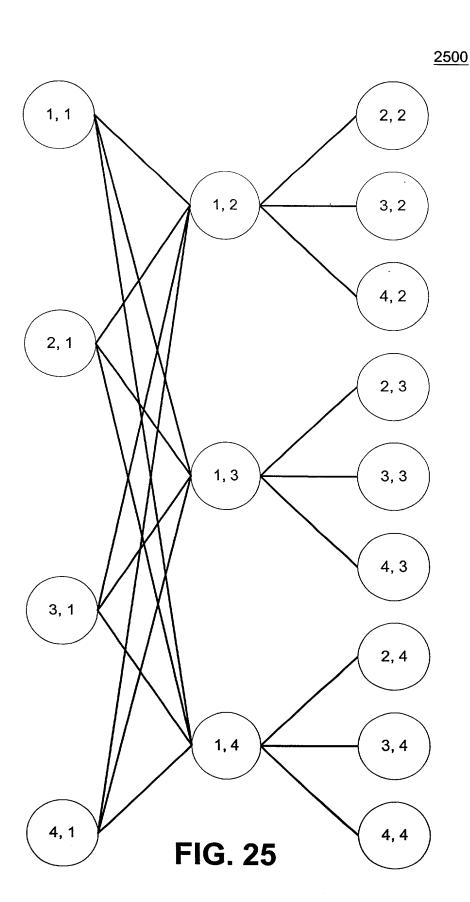
2900

Figure 29

U.S. Patent Application No. 10/005,783
Applicant: Lewis et al.
Title: Methods And Systems For Developing
Data Flow Programs
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```
      ╭─────────────╮
     (    Begin      )
      ╰──────┬──────╯
             │
             ▼
   ┌─────────────────────┐
   │ Pause execution of  │
   │  data flow program  │
   │                     │
   │            3002     │
   └──────────┬──────────┘
              │
              ▼
   ┌─────────────────────┐
   │ Wait for single step│
   │     indication      │
   │                     │
   │            3004     │
   └──────────┬──────────┘
              │
              ▼
   ┌─────────────────────┐
   │ Selecte and execute │
   │  code for next node.│
   │                     │
   │            3006     │
   └──────────┬──────────┘
              │
              ▼
      ╭─────────────╮
     (     End       )
      ╰─────────────╯
```

Figure 30

3000

U.S. Patent Application No. 10/005,783
Applicant: Lewis et al.
Title: Methods And Systems For Developing
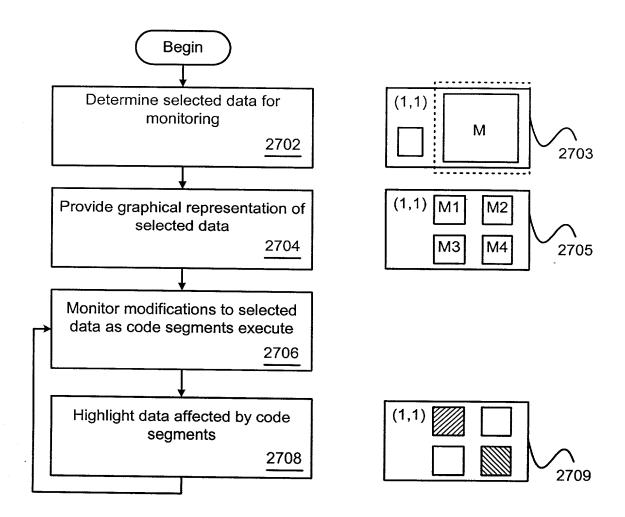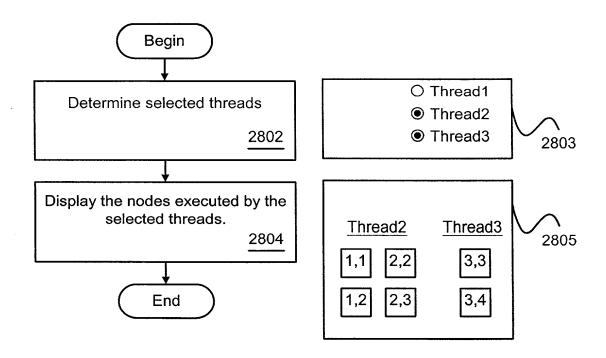Data Flow Programs
Docket No: 30014200-1005
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```
        ┌─────────────┐
        │    Begin    │
        └──────┬──────┘
               │
               ▼
    ┌────────────────────┐
    │  Pause execution of│
    │  data flow program │
    │        3102        │
    └─────────┬──────────┘
              │
              ▼
    ┌────────────────────┐
    │  Output DAG status │
    │   information to    │
    │  secondary storage. │
    │        3104        │
    └─────────┬──────────┘
              │
              ▼
    ┌────────────────────┐
    │   Receive replay   │
    │     indication     │
    │                    │
    │        3106        │
    └─────────┬──────────┘
              │
              ▼
    ┌────────────────────┐
    │  Load DAG status   │
    │   information from  │
    │  secondary storage  │
    │        3108        │
    └─────────┬──────────┘
              │
              ▼
    ┌────────────────────┐
    │    Replay node     │
    │ execution using DAG│
    │  status information │
    │        3110        │
    └─────────┬──────────┘
              │
              ▼
        ┌─────────────┐
        │     End     │
        └─────────────┘
```

3100

Figure 31

U.S. Patent Application No. 10/005,783
Applicant: Lewis et al.
Title: Methods And Systems For Developing
Data Flow Programs
Docket No: 30014200-1005
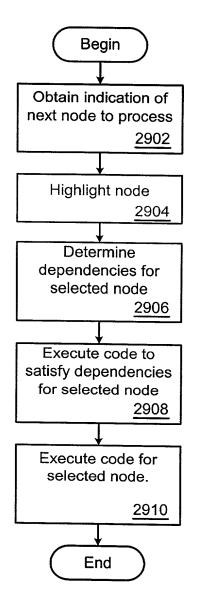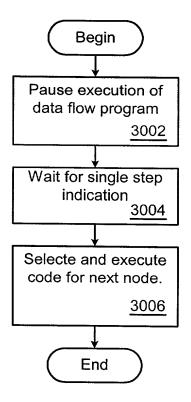Sheet 36 of 39 Sheets

Begin

Pause execution of
data flow program

3202

Receive indication of
dependency to add or
delete

3204

Add or delete
dependency

3210

Enqueue nodes for
execution

3212

Continue execution

3214

End

3206

1,1   2,2

1,2

4,1

3208

1,3

1,1   2,2
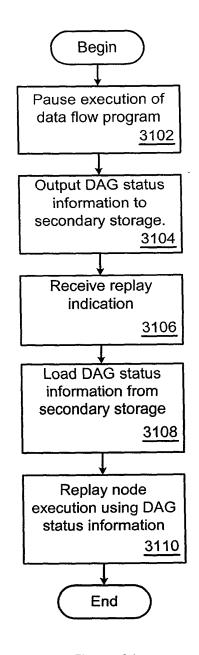
1,2

4,1

1,3

3200

Figure 32

U.S. Patent Application No. 10/005,783
Applicant: Lewis et al.
Title: Methods And Systems For Developing
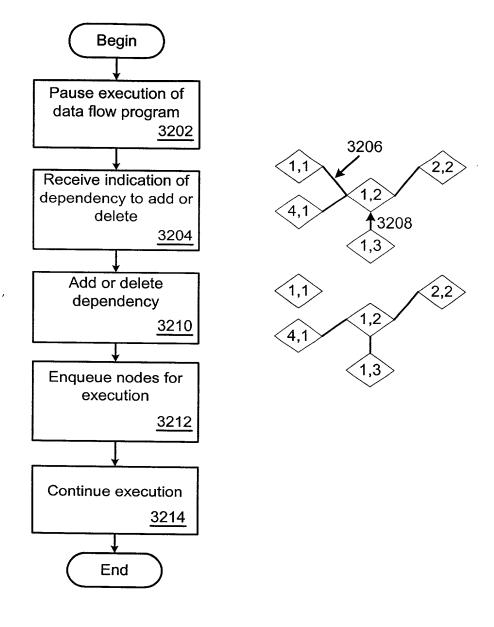Data Flow Programs
Docket No: 30014200-1005
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```
                    ┌──────────────┐
                    │    Begin     │
                    └──────┬───────┘
                           │
                           ▼
              ┌────────────────────────┐
              │   Receive node and     │
              │   breakpoint type      │
              │   indication           │
              │                        │
              │              3302      │
              └───────────┬────────────┘
                          │
                          ▼
              ┌────────────────────────┐
              │   Set breakpoint for   │
              │        node            │
              │                        │
              │              3304      │
              └───────────┬────────────┘
                          │
                          ▼
              ┌────────────────────────┐
              │  Monitor for breakpoint│
              │ conditions during node │
              │       execution        │
              │              3306      │
              └───────────┬────────────┘
                          │
                          ▼
              ┌────────────────────────┐
              │   Halt program when    │
              │  breakpoint condition  │
              │       met    3308      │
              └───────────┬────────────┘
                          │
                          ▼
                    ┌──────────────┐
                    │     End      │
                    └──────────────┘
```
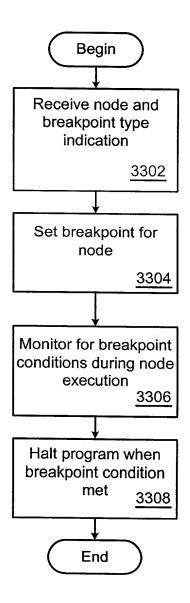
Figure 33

3300

U.S. Patent Application No. 10/005,783
Applicant: Lewis et al.
Title: Methods And Systems For Developing
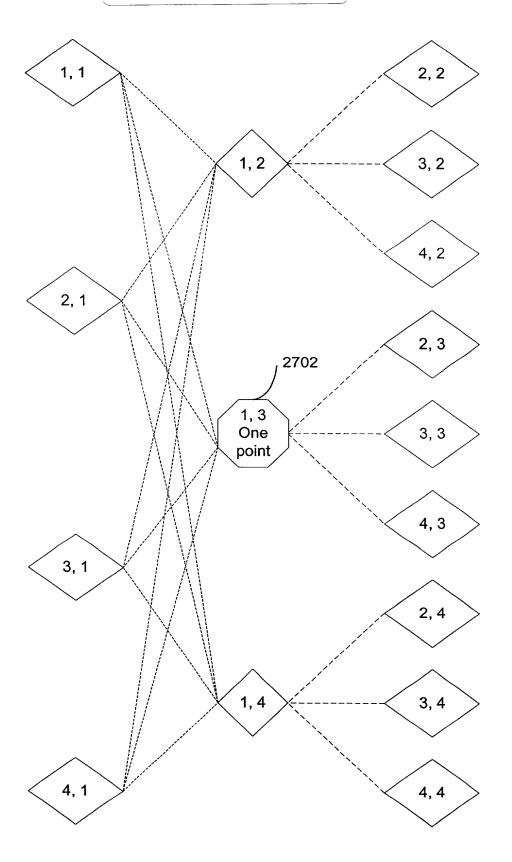Data Flow Programs
Docket No: 30014200-1005
Sheet 38 of 39 Sheets

Figure 34

3400

U.S. Patent Application No. 10/005,783
Applicant: Lewis et al.
Title: Methods And Systems For Developing
Data Flow Programs
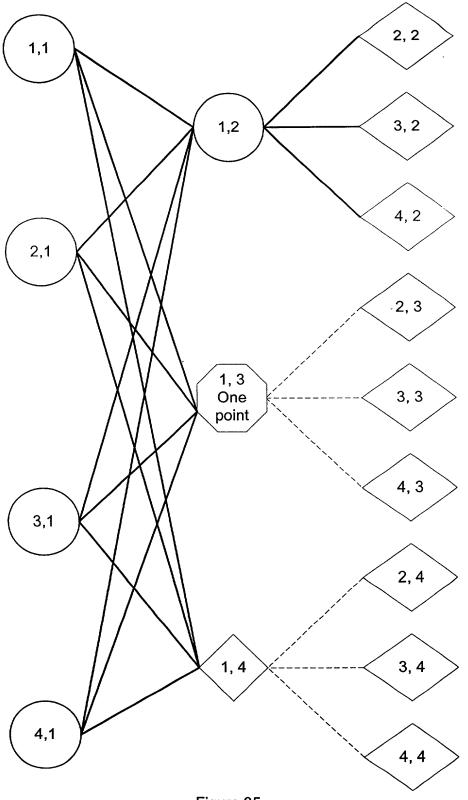Docket No: 30014200-1005
Sheet 39 of 39 Sheets

Figure 35

3500